HURRICANE IWA EXPERIENCE AND COASTAL FLOOD HAZARD ESTIMATION IN HAWAII

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Abstract

This report comments on a recommendation regarding the study of hurricane frequency in Hawaii and the incorporation of hurricane flood experience with tsunami experience in the estimation of the coastal flood hazard in the National Flood Insurance Program (NFIP). The recommendation is one in the report of a Federal Emergency Management Administration interagency team investigating the effects of Hurricane Iwa. The comments are those of a person who has been involved, substantially but indirectly, in the development of the NFIP estimates of the tsunami hazard, but has no special knowledge about hurricanes and only indirect information on Iwa's effects.

Poipu, Kauai, is selected for investigation of methods and effects of incorporating the hurricane experience in coastal flood evaluation because that site probably represents an extreme example of discrepancies between the extent of coastal flooding estimated on the basis of tsunami experience alone and the flooding due to Iwa. The investigation results suggest that, for the 100-year recurrence interval of principal concern in the NFIP, the near-shore flood height at Poipu should be increased significantly in the light of Iwa experience, but not to the heights reached by Iwa's wave.

Information is presented on five high-wave events preceding Iwa, including two tsunamis, whose records are pertinent to but have not previously been used in estimating the coastal flood hazard at Poipu.

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Introduction

An "Interagency Flood Hazard Mitigation Report in Response to the November 27, 1982, Disaster Declaration" (FEMA, 1982) recommends that consideration be given to revising, for some Hawaiian coasts, the "base flood elevations" shown on the Flood Insurance Rate Maps (FIRMS) of the National Flood Insurance Program (NFIP). In the NFIP, the base flood is that whose average recurrence frequency is one per 100 years. What clearly is contemplated is the revision, not only of the estimated heights of expectable 100-year flooding, but of the horizontal extent of this flooding, along certain parts of the coast. This paper concerns the advisability, extent, and certain aspects of the methodology of incorporating Hurricane Iwa information in NFIP reestimation of the coastal flood hazard in Hawaii.

The coastal flood hazard indicated by the present FIRMS represents directly the flooding due to tsunamis alone--the flooding due to future tsunamis being estimated on the basis of past tsunami experience. The estimation of the tsunami hazard has been primarily the responsibility of the US Army Corps of Engineers (COE). However, I have been involved in the process:

1) as one directly or indirectly responsible for the recording of a substantial part of the information on the major tsunamis of the last nearly 40 years that has been used in the COE analysis;

2) as a critic of the data and analytic procedures used initially in the analysis;

3) as a contributor to the revision of the analytic procedures in certain details; and

4) as a compiler of further information on historic tsunamis, supplementing and in some cases correcting that initially used in the analysis.

The recommendation for consideration of revision of the FIRMS is substantially in agreement with a recommendation I made in a meeting with the team responsible for the preparation of the Interagency Report.

It is primarily because of my indirect involvement in the estimation of tsunami hazard in the NFIP and in the development of the recommendation regarding the use of Iwa information in modifying the estimation that I have decided to prepare this paper.

I am not an expert on hurricanes, I have not been involved in the recording of such information, and my only information on the coastal flooding due to Iwa has been obtained second or third hand. Such data as I cite in this paper should therefore be regarded, as exemplary generally, only in principle, and exemplary in actual application only to the extend it is corroborated from more reliable sources. The use of the first person singular in the paper is intended to reflect recognition of the limitations of my personal knowledge.

The Interagency Report recommendation

The recommendation referred to above is as follows (FEMA, 1982, p. 8):

Work Element I:

> Establish, if feasible, a site specific hurricane frequency for the Hawaiian Islands.
>
> Background: The U.S. Army Corps of Engineers will conduct a preliminary

analysis to determine the change to the base flood elevation on Kauai to the existing Flood Insurance Rate Map, by incorporating the elevation data from Hurricane Iwa into their computer program used to generate the Kauai Flood Insurance Rate Map.

If the U.S. Army Corps of Engineers or other detailed analyses shows a significant change to the base flood elevation then, if feasible, a hurricane frequency analysis should be accomplished. If the hurricane frequency analysis indicates the existing base flood elevation (currently based on tsunami only) is lower than the base flood elevation resulting from hurricane, the flood insurance study should be evaluated and revised accordingly.

Pertinence of hurricane flooding to coastal-flood hazard estimation in the NFIP

As noted in the recommendation, the base flood elevations (100-year flood elevations) place to place along the coast that are now indicated on the FIRMS, and also the horizontal extent of flooding (coastal high hazard zone), are based on tsunami expectations alone. I was not privy to the discussions that lead to the decision to reflect the tsunamis expectations alone but the decision seemed sensible to me for two reasons:

1) No compilations of historical data on flooding by storm waves, storm-wave setup, or storm surges are available for Hawaii comparable with published compilations of historic tsunami flooding.

2) Storm waves and associated storm-wave set-up might, along many coastal segments, result in flooding more extreme than that of tsunamis for average recurrence intervals of up to several decades, but not for recurrence frequencies on the order of 100 years; and prior to the occurrence of Iwa, is seemed doubtful that the 100-year flooding caused by hurricane storm-surges and hurricane wave-setup would exceed the 100-year flooding caused by tsunamis in Hawaii.

However, it seems intended that the NFIP be applied to flooding of any type, whether by fresh water from streams or by salt water from the sea; and that, with respect to the latter, whether as the result of tsunamis, storm waves, storm-wave setup, or storm surges. If this is correct, then the tsunami information used in the estimation of the coastal flood hazard in the NFIP should be regarded as a proxy for coastal flooding in general. To the extent that the tsunami information is found to be an inadequate proxy, it should be supplemented by information on other types of flooding from the sea.

As I will show later, the heights reached by sea water during Iwa are, at least at one site on Kauai, the equal of those expected to be reached by a tsunami only once in 500 to 1000 years. It seems almost inescapable that along the part of the south coast of Kauai including that site, and perhaps along two or three parts of that coast and along the southwest coast of Oahu, the Iwa experience indicates the inadequacy of the tsunami proxy for flooding from the sea in general. The questions to be addressed then are:

1) Along what Hawaiian coasts is the proxy inadequate;

2) How may the hazard of coastal flooding, other than by the tsunamis of the sort already taken into account in the NFIP, be best evaluated; and

3) How may non-tsunami coastal flood information best be merged with tsunami flood information.

The first of these questions can be addressed only when the answers to the second and third have been provided and put to use. Before addressing either the second or third question, it seems pertinent to make several general comments.

General comments

Site-specific vs regional hazard evaluation

Work Element I, quoted above, quite properly stresses the importance of site-specific estimation in the evaluation of flood hazards in the NFIP. It is quite clear that, in the case of tsunami hazards, some places on the Hawaiian coasts are much more liable to any particular extent of flooding than other places. It would be irrational to assume that the hazard was everywhere identical in estimating risks for insurance purposes or in establishing controls on land use. However, regional analysis have their place in the estimation of site-specific hazards and, as will be shown, there is a limit to the detail to which site-specific estimation of the hazard is practicable.

Importance of historic information on coastal flooding

It is an implicit premise in the estimation of flood hazards in the NFIP that estimates of future hazards must be based on past experience--directly, or indirectly through inter-site or inter-region transfers. As will be shown, the use of sophisticated models has a place in the process of transferring historic experience place to place. However, in the case of tsunamis, and I suspect even more in the case of hurricanes, the synthetic local historic data derived by models are trustworthy only to the extent the models can be calibrated by reference to actual local experience.

Historic coastal flood records pertinent
to but not yet used in the NFIP estimation

As noted earlier, the hazard of ordinary storm waves and the setup of such waves is serious in Hawaii. However, I still know of no evidence that indicates that the flooding due to such waves is significant in the estimation of the hazard associated with the 100-year recurrence interval that is standard in the NFIP. Hence such flooding will not be further discussed in this paper.

As indicated earlier, the experience of Hurricane Iwa must surely be taken into account in the revision of the NFIP coastal flood hazard estimates. However, Iwa is not the only hurricane known in Hawaiian history. The experience of Hurricane Dot, which occured in 1959, should also be taken into account, although the intensity of the flooding it caused was very small compared with that caused by Iwa. There have been, in addition, several occurrences of abnormally high waves whose identity as extraordinary non-hurricane storm waves, hurricane waves, or tsunamis is not certain. The flooding due to some of these waves has already been taken into account in the NFIP because of the possibility that they represented locally generated tsunamis.

All of the known historic tsunamis that are likely to be significant in determining 100-year flood limits have already been taken into account in the NFIP estimates of coastal flooding. However, not all have been taken into account in the estimates for all coasts on which their flooding was significant. Specifically, the flooding due to two tsunamis from Japan, although taken into account in the original or revised NFIP estimates for the coasts of the island of Hawaii, have not been taken into account in the estimates for the south coast of Kauai where they had significant heights.

Tsunami, hurricane, or combined tsunami-hurricane flood limits

The second paragraph of Work Element I suggests that "the flood insurance study should be ... revised" only if the "existing base flood elevation (currently based on tsunami only) is lower than the base flood elevation resulting from hurricane." It is my opinion that the revision should be made if the extent of 100-year coastal flooding due to the combination of tsunami and hurricane experience exceeds the extent due to tsunamis alone, whether or not the extent of 100-year hurricane flooding alone exceeds the extent of tsunami flooding.

Tsunami hazard evaluation in the NFIP

The height-frequency analyses in the NFIP are based on the concept that the recurrence frequencies of tsunamis with runup heights equal to or exceeding certain values vary linearly with the exponentials of the runup heights. This concept stems originally, so far as I have been able to determine, from an informal report of mine (Cox, 1964) on the frequency-height distribution of tsunamis at Hilo. I found that the Hilo record closely resembled the exponential model except for tsunamis to which a power-law model applied. The concept was picked up by Wiegel (1965, 1970) and applied by him not only to the record at Crescent City, California, of the runup heights of tsunamis originating elsewhere, but to the record of maximum runup heights of Japanese tsunamis along the coasts of Japan. From Wiegel the concept was picked up by others. By various authors it has been used in analyses of: 1) runup heights in the vicinity of a single site for tsunamis originating elsewhere; 2) maximum runup heights along a regional coast for tsunamis originating elsewhere;, and 3) maximum runup heights along a regional coast for tsunamis originating along that coast.

It can be proved on the basis of only a little examination that the model cannot apply rigorously in all three cases. Physically it would seem that the most nearly rigorous application would be to the distribution of runup heights in the region of generation of tsunamis, assuming that the intensity distribution of tsunami-generating forces in each tectonic region were exponential and assuming proportionality between this intensity and the maximum runup heights of the tsunamis. At a place distant from the generating region, the distribution of heights of tsunamis from that region might also be expected to be exponential. However, the distribution of heights at that place of tsunamis from several source regions could be strictly exponential only if the slope coefficients of the distributions for all of the source regions were identical. Although assumed by some authors, this assumption is unlikely to be valid, because the slope coefficients of earthquake magnitude distributions are quite different in various tectonic regions.

It should be noted that the observed heights in the historic record are not strictly speaking tsunami runup heights, but the heights to which flooding occurs at the time of each tsunami as the result of the combination of the tsunami waves, the tide, and whatever ordinary waves are present. Exact fit to an exponential model or any other simple model should therefore not be expected. However, the invalidity of an assumption of rigorous applicability of the exponential model to the runup heights, at or in the vicinity of a particular place, of the populations of tsunamis from all contributing source regions does not necessarily destroy the utility of the model applied in this way as an approximation.

Ideally the levels to which coastal flooding should be expected at different distances inland from the shoreline at a particular site should be estimated by frequency analysis of historic records of observed levels of flooding at each distance over a period considerably longer than 100 years. The records used in the estimation of 100-year tsunami flood levels in the NFIP are predominantly synthetic (derived from models) rather than observational. Furthermore, the actual estimation differs from the ideal in that, for each site, the frequency analysis has been applied to the "runup heights" at a single distance inland from the shoreline, generally 200 feet although such observational data as may be available may pertain to other loci (Cox, 1979). The models used in producing the site-specific synthetic height records and the site-specific frequency analyses are those of Houston et al. (1977). They applied their frequency analysis for each site to the 10 highest of the estimated tsunami runups in the historic record since 1837. The datum for the heights is mean sea level (msl). The heights of flooding of local tsunamis, referred in original reports to post-event sea levels, have been increased at my suggestion (Cox, 1979) by the amount of subsidence on coasts that subsided at the time of the tsunamis.

The 100-year flooding at spots at other distances from the shoreline at the site are estimated from the 100-year runup height estimated for the single spot, taking into account the slope and roughness of the terrain along a normal to the shoreline using a model developed by Bretschneider and Wybro (1976). No allowance is made for flooding other than that normal to the shoreline. Furthermore, no allowance is made for differences in the flood profiles transverse to the shoreline that might be expected even with tsunamis having the same near-shore height but different wave periods.

Combined tsunami and hurricane flood hazard evaluation

To investigate the nature and extent of the problems that may be encountered in incorporating with tsunami experience the experience of Hurricane Iwa and other historic events not incorporated in the present NFIP estimates of coastal flooding, I have examined the record at Poipu, Kauai, selecting this site because it may exemplify the greatest discrepancy between the present NFIP estimate of the 100-year height and the flood heights due to Iwa.

Near-shore flood heights at Poipu

The 10 highest near-shore runups for Poipu in the record analyzed by Houston et al. (1977) were those of the following tsunamis (listed in order of decreasing order of height):

Year	Source	Year	Source
1957	Aleutians	1942	Kamchatka
1946	Aleutians	1877	Chile
1960	Chile	1952	Kamchatka
1923	Kamchatka	1868	Chile
1837	Chile	1964	Alaska

Of these ten, only the height of the 1957 tsunami represents an observed value. The near-shore frequency distribution now assumed for this site in the NFIP is shown in figure 1. The 100-year runup height indicated by this distribution is 6.2 ft msl.

Houston et al. assumed that the Japan tsunamis of 1896 and 1933 had insignificant runup heights at Poipu and elsewhere on the south coast of Kauai. However, both of these tsunamis had estimated Poipu runup heights on the order of the third highest assumed by Houston et al. (Cox, 1980). The near-shore height-frequency distribution resulting from substituting the heights of these two tsunamis for the two smallest in the NFIP analysis (also shown in figure 1) indicates a 100-year tsunami runup of 6.3 feet.

My information on Iwa flood heights at Poipu has come from Saul Price ot the National Weather Service and from Alison Kay, a University of Hawaii marine biologist, who owns a house at Poipu and who visited Poipu a couple of weeks after Iwa occurred. It is my understanding that the height of the debris line at the limit of inundation, about 600 feet inland from the shoreline, was about 8 feet msl, but that at the Waiohai Hotel, close to the shore, there was a height of 11 feet msl. As indicated by figure 1 the average recurrence intervals of tsunamis with runups equal to or exceeding 8 and 11 feet at Poipu are, respectively, on the order of 500 and 1000 years. However, at the Kay house, on the slope of Makahuena point at the eastern end of Poipu, there was evidence of wave runup to a height of at least 30 feet msl.

Dr. Kay informs me that Hurricane Dot (1959) resulted in flooding to about 6 feet above msl. at Poipu.

Frequency distributions including the 6-foot Dot height and, alternatively, the 8-and 11-foot Iwa heights have been added to figure 1. The exponential model fits the record with the 8-foot Iwa height, as well as it fits the record of the 10 highest tsunami runups. The 100-year height indicated by this record is 7.6 feet msl. However, the locus of the 11-foot Iwa height fits better the locus assumed for tsunami runup heights. If that height is substituted for the 8-foot value, the fit of the exponential model is not quite so good, but still better than the fit for the tsunami runup heights estimated for many sites. The 100-year height indicated in the case is 9 feet msl.

The 30-plus-foot height at the Kay house falls off-scale for figure 1. If that height were substituted for the 8- or 11-foot heights for Iwa, the use of the exponential model would result in an estimate of 17½ feet for the 100-year near-shore height. However, the fit of the exponential model in this case would be very poor. Furthermore, the height experience at the Kay house is clearly not representative of the experience at the central Poipu site to which the rest of the data pertains. According to Kay, the 30-foot height was reached by a single wave rising above the already generally raized water level. This, however, is not sufficient grounds to disregard the anomalous height, because the "tsunami heights" to which frequency analysis applied reflect combinations of tsunami and short-period waves and because the heights recorded for Iwa undoubtedly do also. However, it is not clear to me that the 30-plus-foot height has any statistical significance, and if it is somehow to be incorporated in the coastal flood hazard evaluation it would seem best to treat the site of the Kay house as one distinct from the rest of Poipu.

For central Poipu, then, the best estimate of the 100-year near-shore flood height seems to be about 9 feet msl.

Transverse flood profile and inundation limit at Poipu

Assuming the validity of the Iwa and Dot data I have used and of the 9-foot estimate of the 100-year near-shore flood height, the problem to be faced at Poipu is the estimation of the 100-year flood profile transverse to the shore and the horizontal extent of 100-year flooding. I can offer only some general comments on this problem and not a definite recommendation for coping with it.

Over relatively flat terrain, the downward inland slopes of the runup profiles of tsunamis, which characteristically have wave periods in the range from about 10 to about 60 minutes, should be expected to be steeper than the slope of the runup profile of a hurricance storm surge, which might have a duration of between an hour to a few hours. The extent to which the Iwa flooding at Poipu and elsewhere resulted from a storm surge of such duration seems still unclear. However, the average slope between the Iwa flood heights of 11 feet near shore and 8 feet at the inundation limit about 600 feet from shore may well be smaller than the average slope that would be estimated by the Bretschneider and Wybro (1976) model for tsunami runup profiles at Poipu.

It must be recognized that the 9-foot estimate at Poipu is not the height of either a tsunami or a storm surge, but a height reached on the average once in a 100 years whether during a tsunami or a hurricane. Before I recommended a method for estimating the corresponding flood profile, even if I were inclined to make such a recommendation, I would want to see how well or how poorly the Bretschneider and Wybro model fits the Iwa profile of flooding at Poipu.

Near-shore flood heights and transverse flood profiles elsewhere

I have reviewed the Houston et al. estimates of the near-shore runup heights of historic tsunamis and the longitudinal 100-year tsunami runup profile implied by the slope and intercept coefficiencts they have published for the site-specific height-frequency distributions for the entire south coast of Kauai. So far as I can determine, there are no inconsistencies. They did not include the tsunamis of 1896 or 1933 in the records on which the frequency distributions were based. Inclusion of these tsunamis would probably make even less difference in the vicinity of Port Allen than at Poipu and between there and Kukuiula, and still less in the vicinity of Kekaha.

I have not reviewed the 100-year tsunami inundation limits shown on the FIRMS because I have no special competance for such a review.

It is my impression that the tsunami record will be found to be less inadequate as proxy for the record of coastal flooding in general to the west of Kukuiula on Kauai and on the southwest coast of Oahu than it seems to be in the Poipu-Kukuiula coast of Kauai, and that less problems will be encountered on these other coasts in incorporating Iwa experience in revising the coastal flood evaluation for the NFIP.

Additional pertinent historic information

It is clear from the results of efforts to find local contemporary accounts of events that have been reported as tsunamis or "tidal waves" (Cox and Morgan, 1977; Cox 1980) that such efforts are likely to produce information allowing the estimation of flood heights at sites other than those mentioned in the standard geophysical literature, and even corrections to the data presented in that literature. A search for local contemporary accounts of high-wave events other than those reported as "tidal waves" would also be productive but without some focus would entail an enormous effort. At this point in the development of evaluation of coastal flood hazards in the NFIP a geographic focus seems appropriate--a focus on the coasts most seriously affected by Iwa. Likely sources of pertinent information include are persons who have long had, or whose families have long had, residences or other property near the shoreline, and the records of institutions that have had near-shore facilities.

I have made only the barest beginning to a search for such information pertinent to the Poipu vicinity, but I can contribute a little more information than that which is reflected in figure 1, partly as the result of the continuing search for information on reported "tidal waves".

A wharf was probably first constructed at Koloa Landing in 1835 or 1836 when the Koloa Sugar Co. was established and the first Koloa mill was constructed. The Landing remained in active use for at least the balance of the 19th century. One should expect, therefore, that events of extensive wave damage at the Landing would be considered newsworthy. One incident of damage was indeed reported in two newspaper articles.

The first article, in the Pacific Commercial Advertiser of 10 October 1868 read:

> DAMAGE ON KAUAI--By the schooner "Nellie", we learn that the wind which was here until quite fresh last Friday and Saturday 1 - 2 Oct., blew a heavy gale on Kauai. At Nawiliwili considerable damage was done to the cane fields. At Koloa the surf rolled in furiously, tore away the wharf, carried some twenty cords of wood to sea, and did other damage. At Hanapepe four houses were blown down, and at Waimea seven more were destroyed (grass houses?). A portion of the roof of the large church there was

> also blown off. Large number of trees were uprooted, while scores of coconut trees were broken off as if they had been pine stems.

The second article,in the Hawaiian Gazette of 14 October 1868 read:

> THE STORM--The southerly wind and rainy weather that we had in Honolulu, from Sept. 19th to Oct. 8th, prevailed throughout the group. The rains have been copious and abundant, and most favorable for plantation crops. There was not any heavy and damaging wind except on Kauai, where, on Saturday the 3d inst, it blew almost a hurricane, chopping all round the compass. At Lihue about $5,000 dollars damage was sustained in the breaking down of the cane in the fields. The water flume of Mr. G. Wilcox was thrown down. At Koloa, the sea swept away the wharf and caused other damage. The fury of the gale seemed to culminate around Waimea, where several houses were thrown down, and the fine stone church building was extensively damaged. Two-thirds of the northern wall of the building fell, racking and straining the roof frame and otherwise damaging the whole structure. In Honolulu on Thursday the 1st inst., the barometer stood at 30.05, wind N.E. moderate. It fell in the next twenty-four hours to 29.90, wind still N.E. but squally; and on Saturday it chopped suddenly to the S.E. with heavy squalls and rain, and the barometer remained at 29.90 until the following Monday. The weather is still unsettled although the rains have abated.

I came across these articles in further investigation of the reports of the 1 October 1868 occurrence of a "tidal wave" on the southeast coast of Hawaii (Cox and Morgan, 1977). They indicate not only that unusual waves occurred elsewhere during the first few days of October 1868 but that those occurring at some places, at least, may have been associated with a tropical storm and possibly a hurricane. The descriptions of damage at Koloa Landing are meagre, but suggest that the waves must have risen to about 6 feet at the very least, and more probably to something like the runup height of the 1946 tsunami at the Landing, 7 feet msl., or that of the 1957 tsunami there, 8 feet msl. Waves higher than that would probably have caused more damage than was reported. It would seem appropriate on the basis of these reports to include in the 145-year record at Poipu an additional 6' or 7' foot-height event not indicated in figure 1. With the substitution of this height for event for the 10th highest in the frequency distribution taking Iwa and Dot into account would make little difference in the estimation of the 100-year near-shore flood height at Poipu.

Further information of a negative sort is directly pertinent to the evaluation of coastal flooding at Poipu. One of the first houses and possibly the first constructed on the beach at Poipu was that of the Knudsen's. According to Betsy Knudsen Toulon of Koloa, Kauai, the house was first built, probably about 1900 or 1910, on the point seaward of the position it occupied until about 1928 when it was displaced by the resort development at Poipu. The move was not the result of a threat of wave damage, and the house sustained no wave damage at any time, although waves flooded under it during either Hurricane Dot in 1959 or during a 1957 storm (possibly Hurricane Nina in December ?). Clearly no waves with heights approaching those of Iwa occurred during the 70 or 80 years prior to 1982.

I have not commented earlier in this paper on the desirability of a hurricane frequency study such as that recommended in Work Element #1 (FEMA, 1982). I am in no position to estimate how much more can be gained from such a study than has been presented by Shaw (1981) in his report on the history of tropical cyclones in the vicinity of the Hawaiian Islands. I would point out, however, that if the study is to be site specific, such "non-scientific" sources of information as newspaper accounts, personal recollections and diaries, and the records of commercial institutions, should not be overlooked, and that the evidences of the non-occurrence or non-significance of events are as important as the evidences of their significance.

Accessibility of NFIP hazard-estimate background information

It must be clear from the discussion of the nature of the records that have been used in the estimation of the coastal flood hazard and the methods of its analysis that a considerable amount of arbitrariness is inescapable in expressing estimates of the hazard in numerical terms, as is necessary in the NFIP. The extent of arbitrariness will be increased in the case of revised estimates based on the combination of tsunami and hurricane experience.

Considering the inescapable arbitrariness, the NFIP estimates should be open to challenge by those who have reliable information at variance with that used in their preparation. Openness to challenge is, indeed, required by law. However, it has been difficult for persons questioning the validity of the estimates to determine whether what information they may have is pertinent and at variance with that used in the preparation of the estimates because of difficulties in getting access to the bases of the NFIP estimates.

I urge that both the data and the methods used in revising the NFIP estimates of the coastal flood hazard be made conveniently available to those who may wish to investigate their validity.

Conclusions

On the basis of meager information on the Hurricane Iwa experience, and more extensive information on historic tsunamis and the way the latter information has been used in estimating coastal flood hazards in Hawaii in the NFIP, I conclude that:

1. Present estimates of the hazards, based on tsunami experience alone, are inadequate on a few coasts, including specifically that in the vicinity of Poipu, Kauai;

2. The Iwa experience alone cannot be used in estimating the hazard on any coast, and hurricane experiences alone would be an inadequate base for the estimation.

3. Where the present estimates are inadequate, the experience of both tsunamis and hurricanes should be combined in revising them;

4. There will probably be no insuperable barrier to the statistical combination of experience for the revision;

5. Search should be made for and use made of site-specific information supplementing that in standard geophysical literature pertaining to the effects of past tsunamis and hurricanes that had significant effects along the coasts for which the hazard estimates are to be revised.

Acknowledgements

I appreciate the opportunity to discuss in a meeting the FEMA Interagency Flood Hazard Mitigation Team some of the information and suggestions considerably expanded in the paper.

I am grateful to Saul Price, Alison Kay, and Betsy and Alfred Toulon for the information on wave effects at Poipu attributed to them in this report. A draft of the paper was submitted to them and others for review. In its final form, the paper reflects additional comments by Kay and the Toulons and editorial improvements suggested by Jacquelin Miller.

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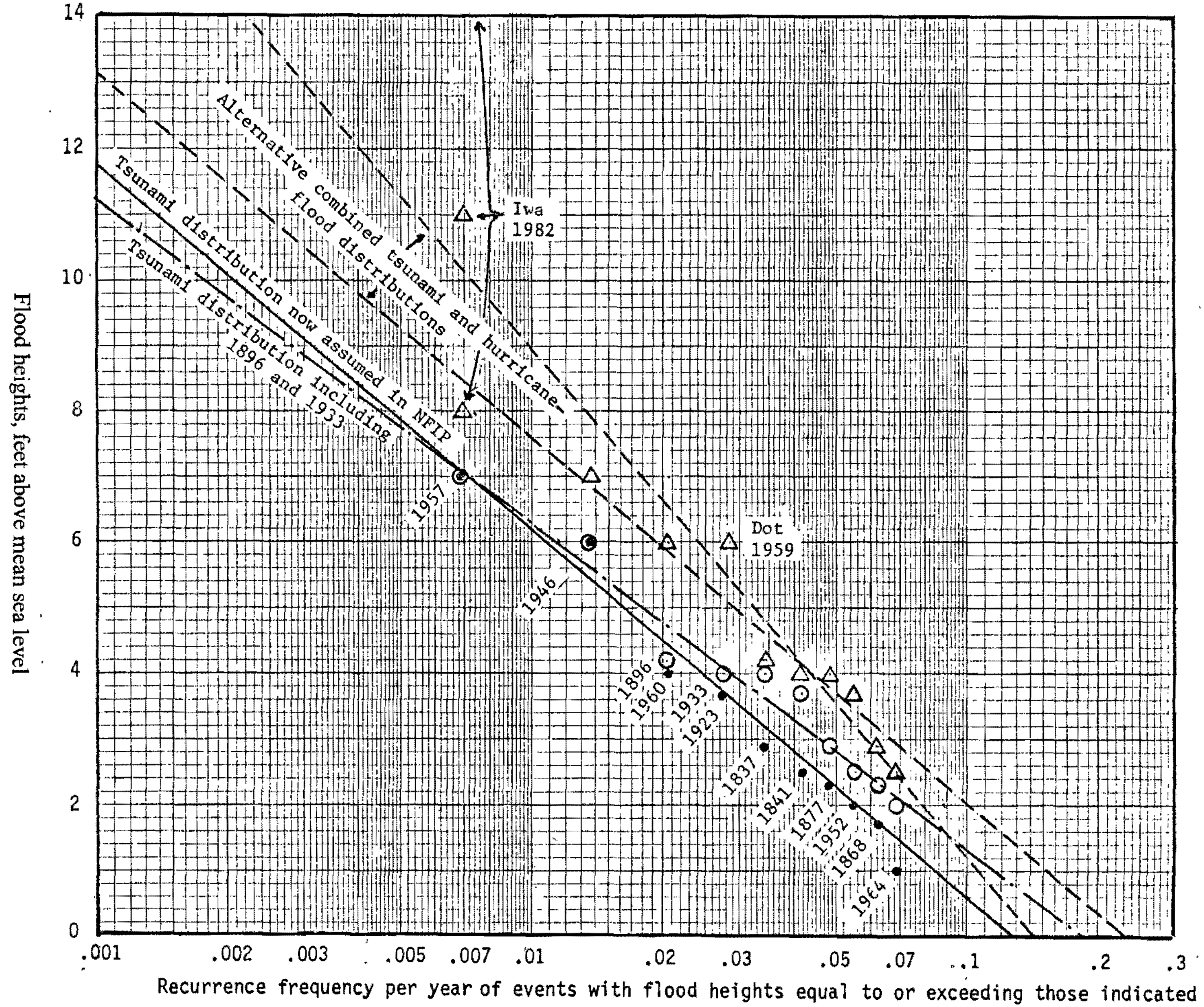

Figure 1. Estimated near-shore coastal flood height-frequency distributions for Poipu, Kauai.